



Materials/Substrate Issues for UV Light Emitters

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Outline

- **Introduction**
- **Review existing Lincoln UV laser applications**
- **HVPE-grown UV Avalanche Photodiodes**
- **Critical substrate issues for UV light emitters**
- **HVPE (Al)GaN templates addressing of these issues**



Examples of Applications for UV III-N Light Emitters

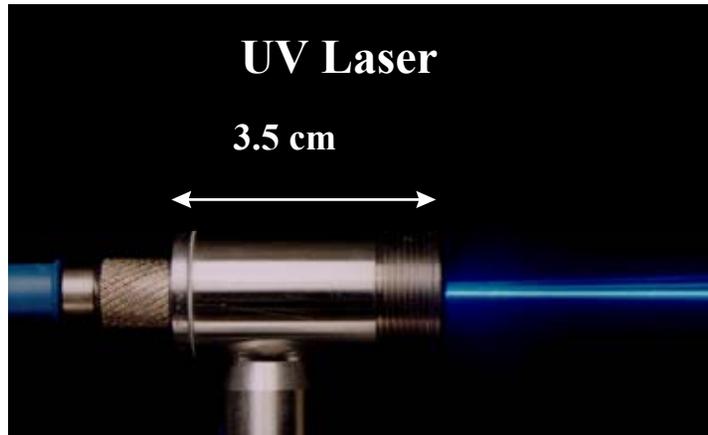
Non-Military

- **Phosphor excitation source for general lighting/displays**
- **Optical storage**
- **Medical**
- **Catalytic activation for air purification**
- **Parallel lithography**

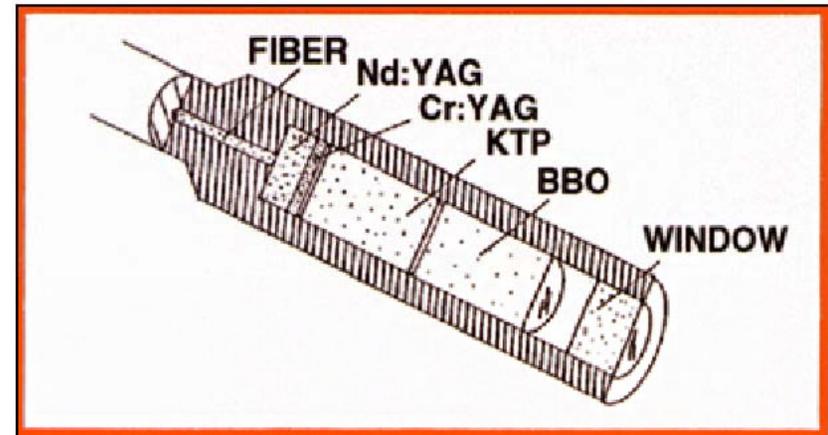


Microlaser

Photograph



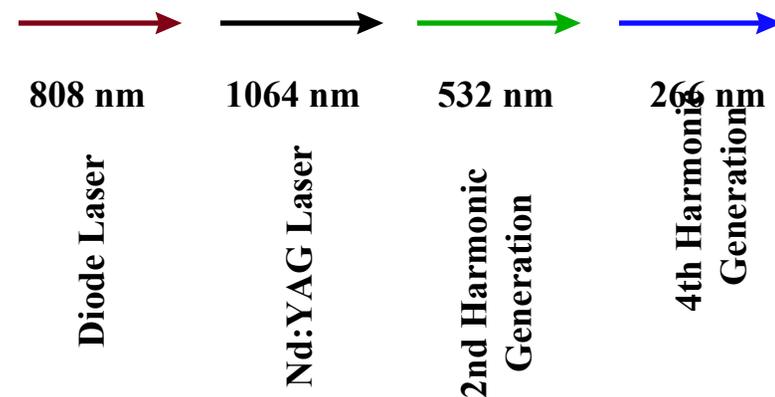
Schematic



Laser Features

- Small, robust
- 10-kHz pulse repetition rate
- < 1 ns pulse duration
- 0.5 - 2 μ J pulse energy @ 266 nm
- Technology licensed to several companies

Laser Wavelengths



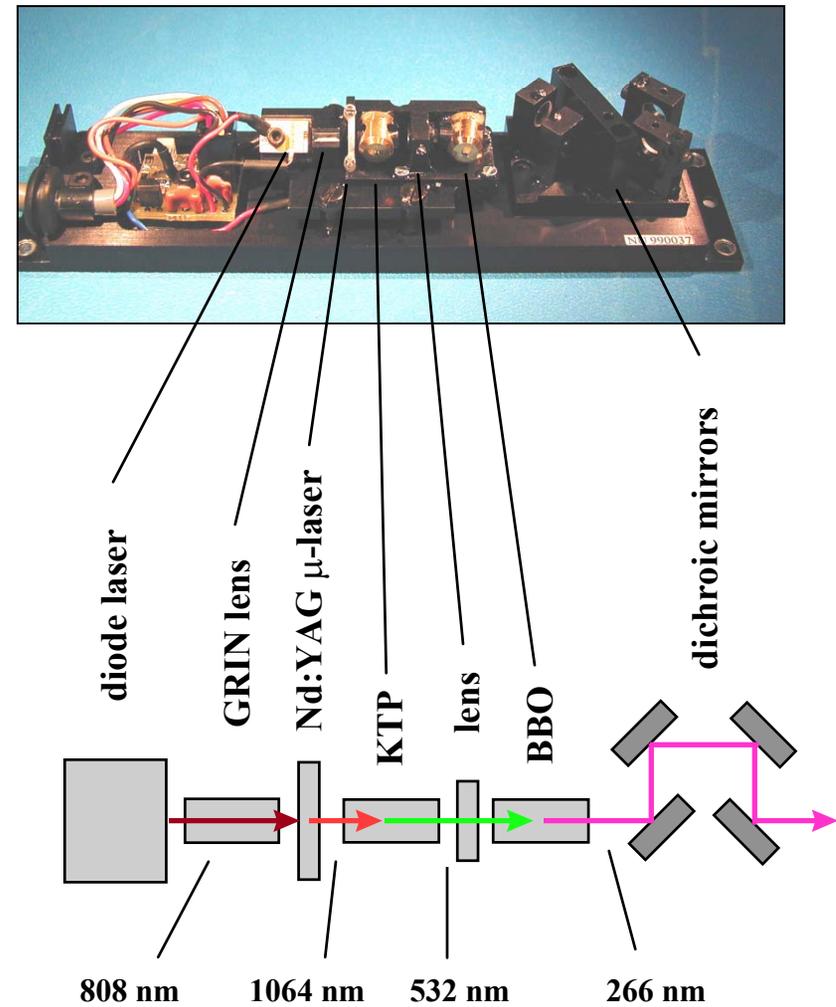


UV Laser

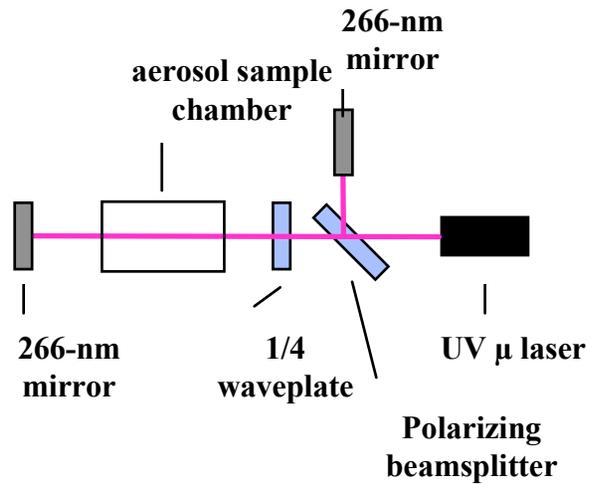
Uniphase Inc. Laser Package



Laser Components



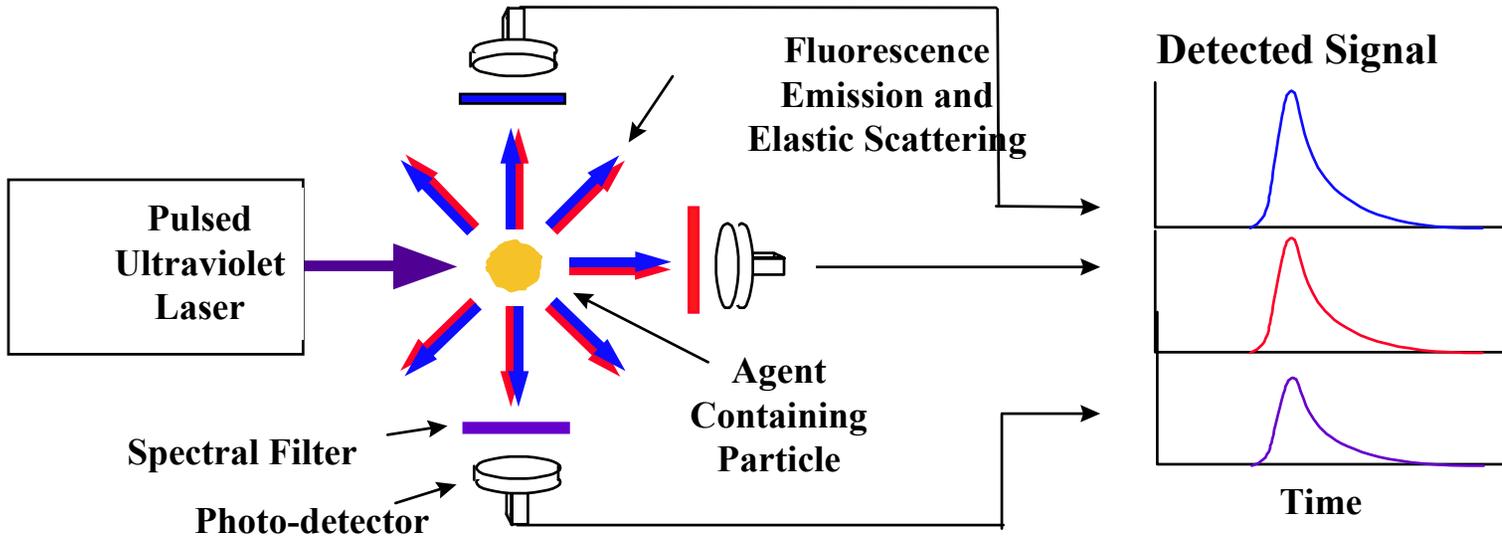
Four Pass Laser Beam Geometry



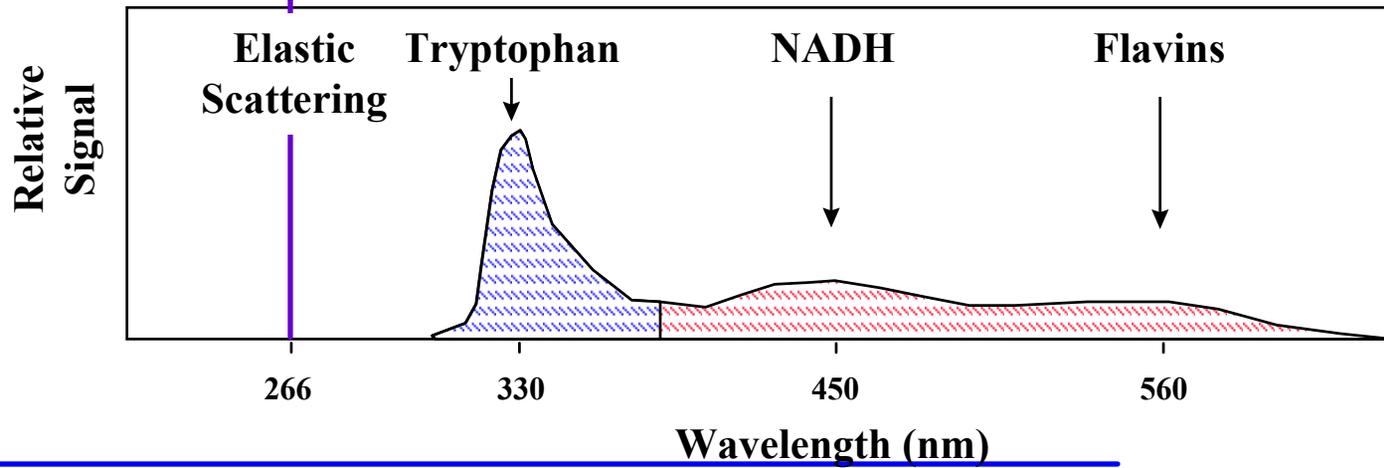
MIT Lincoln Laboratory



Three-channel Sensor Concept



Elastic Scattering and Fluorescence Emission Spectrum





Biological Agent Warning Sensor (BAWS II) Development Progress

Proof-of-concept sensor



Field prototype



Compact package



JFT-3

JFT-4

JFT-4.5

BLWE

Year: 1996

1997

1998

1999



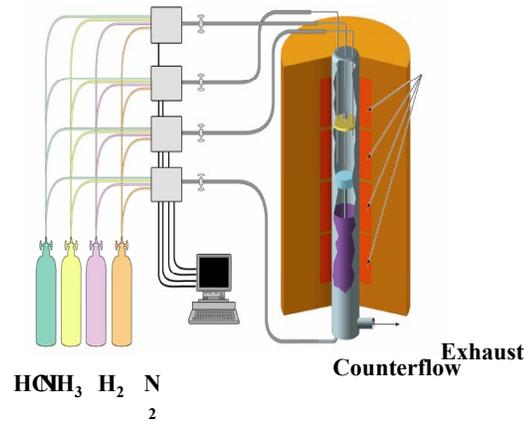
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- **HVPE (Al)GaN templates addressing of these issues**



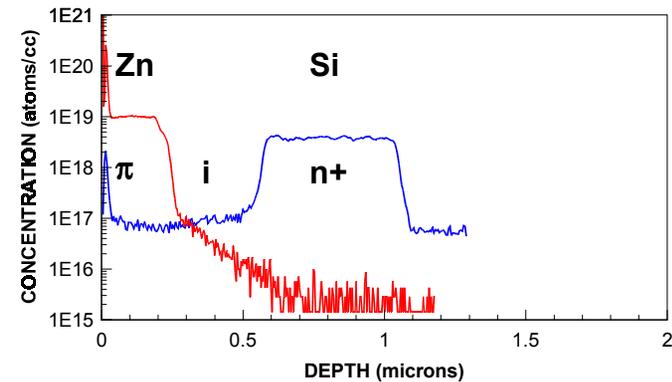
- Rapid growth rate (15-70 $\mu\text{m/hr}$)
- Few impurities from gas sources
- Thick layers enable reduced dislocation densities

HVPE Growth of GaN



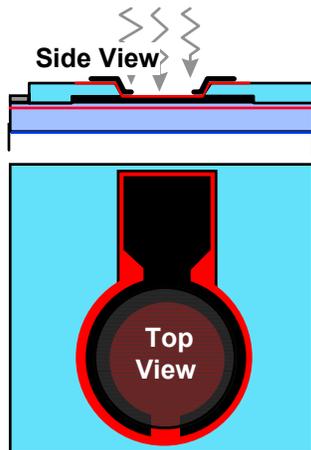
π -i- n^+ Diode Doping Profile

4-Zone Furnace



- Undoped multiplication region thickness from 0.1-1 μm yields breakdown voltages from 30-300V

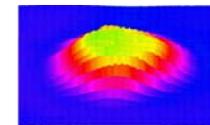
GaN APD Structure



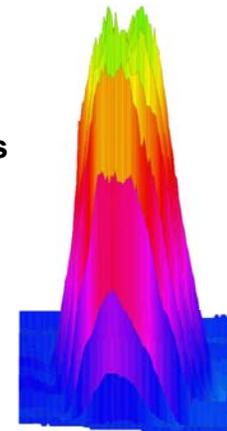
- Thick GaN buffer grown on sapphire substrate
- Si-doped buried layer acts as E-field stop
- Reduced dislocation density has improved APD yield
- Mesa-etched and planar devices have been fabricated

Spatially Uniform Gain Profile

- Uniform multiplication
- Low defect density eliminates microplasmas
- No edge breakdown



Gain = 1

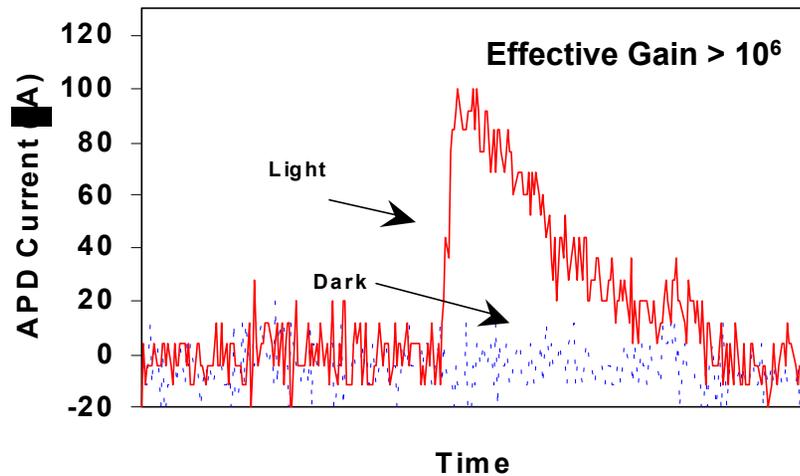


Gain = 10

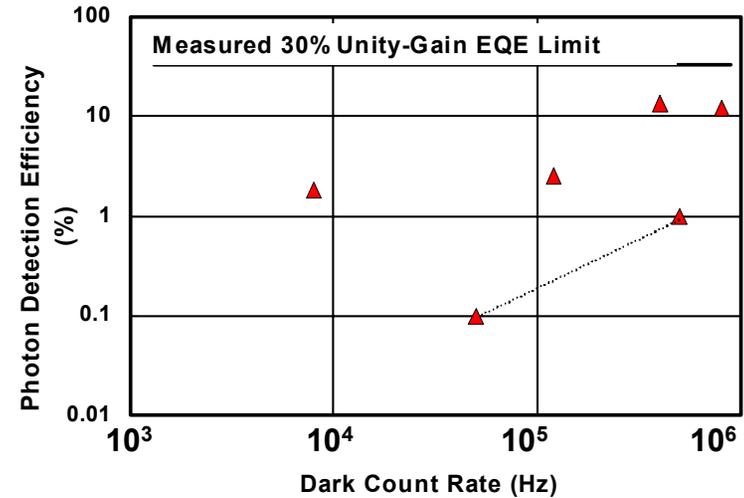


GaN Geiger-Mode Avalanche Photodiodes

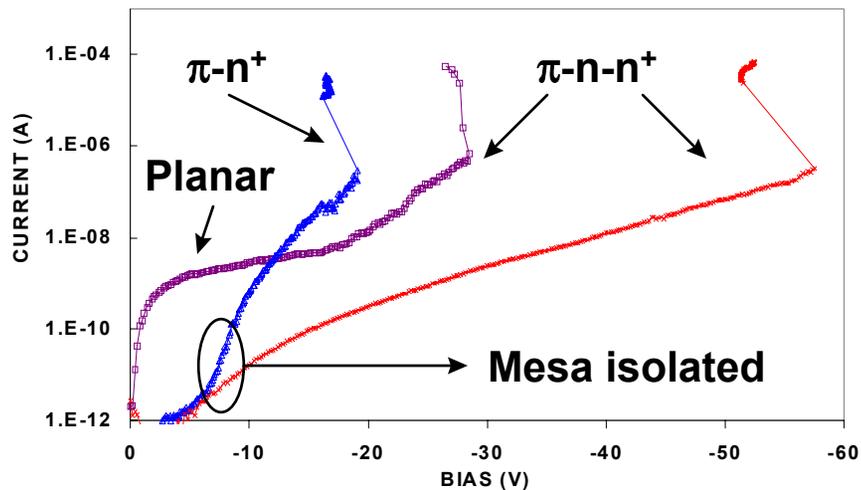
Geiger-mode temporal response



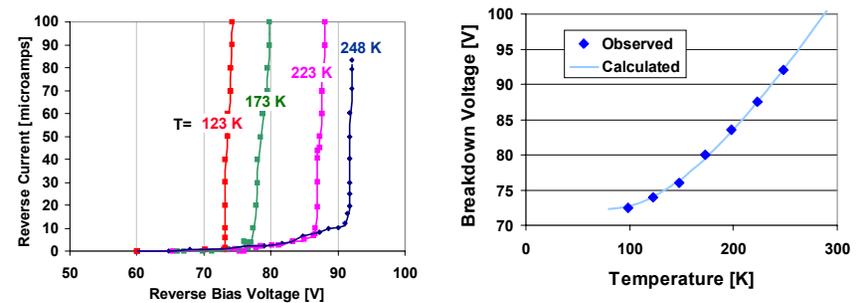
Photon counting performance



Operating voltage reduced to $< 20V$



Reverse breakdown temperature dependence



- Reverse bias breakdown voltage shows a positive temperature coefficient consistent with avalanche breakdown: $dV_B/dT \sim 0.2 \text{ V/K}$ for $T > 200\text{K}$
- Temperature behavior exhibits an effective phonon energy of 42 meV



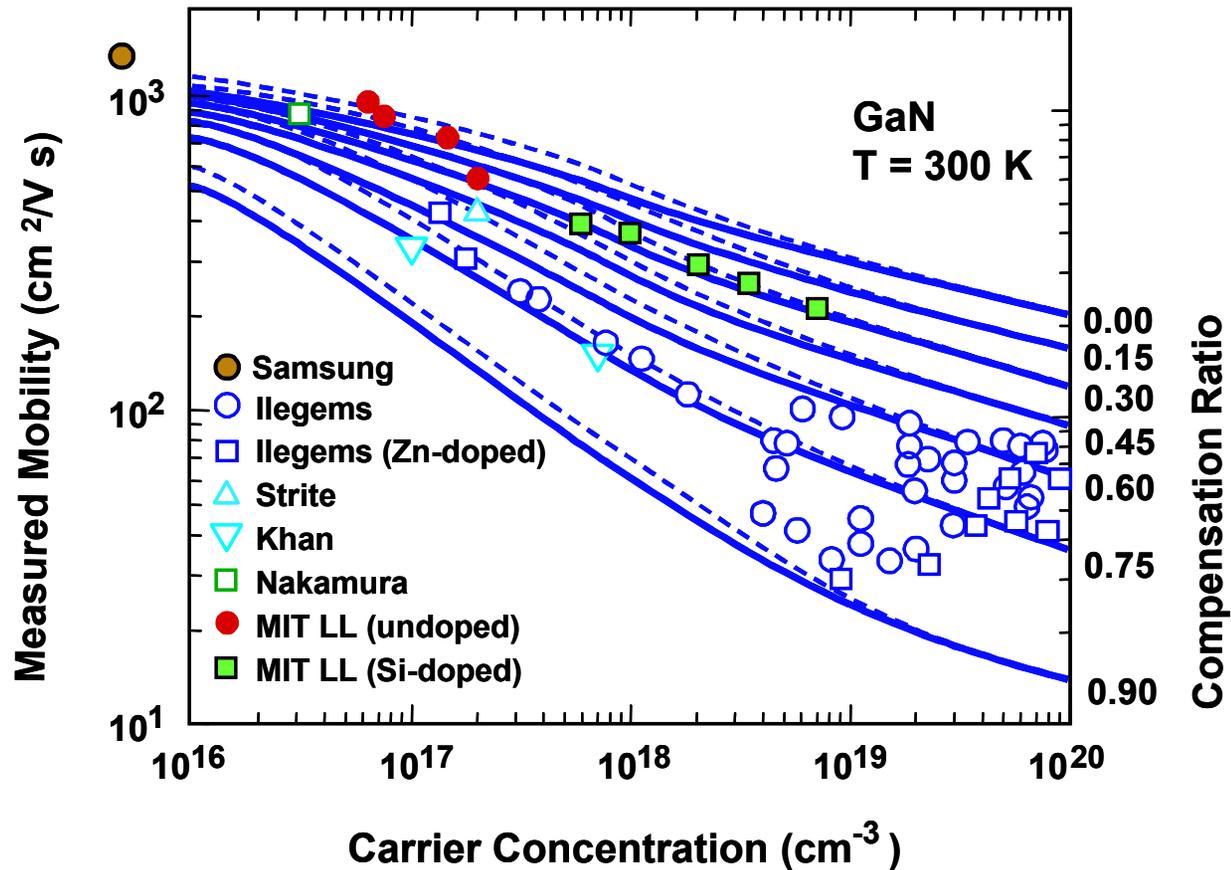
Critical substrate-related issues for UV light emitters

- **Doping**
 - Minimization of series resistance and conduction barriers will be aided by high conductivity homoepitaxial substrates or templates.
- **Defect reduction**
 - Techniques such as ELO will prove difficult with Al-bearing alloys at conventional growth temperatures.
- **Crack suppression**
 - Heteroepitaxial growth related stress will need to be managed to achieve optimized device structures which are crack-free.
- **Thermal management**
 - High expected current densities will necessitate either a high κ bulk substrate or heat spreading layer.

Choice of substrate is likely to have impact on device performance



Doping Behavior of HVPE (Al)GaN Films

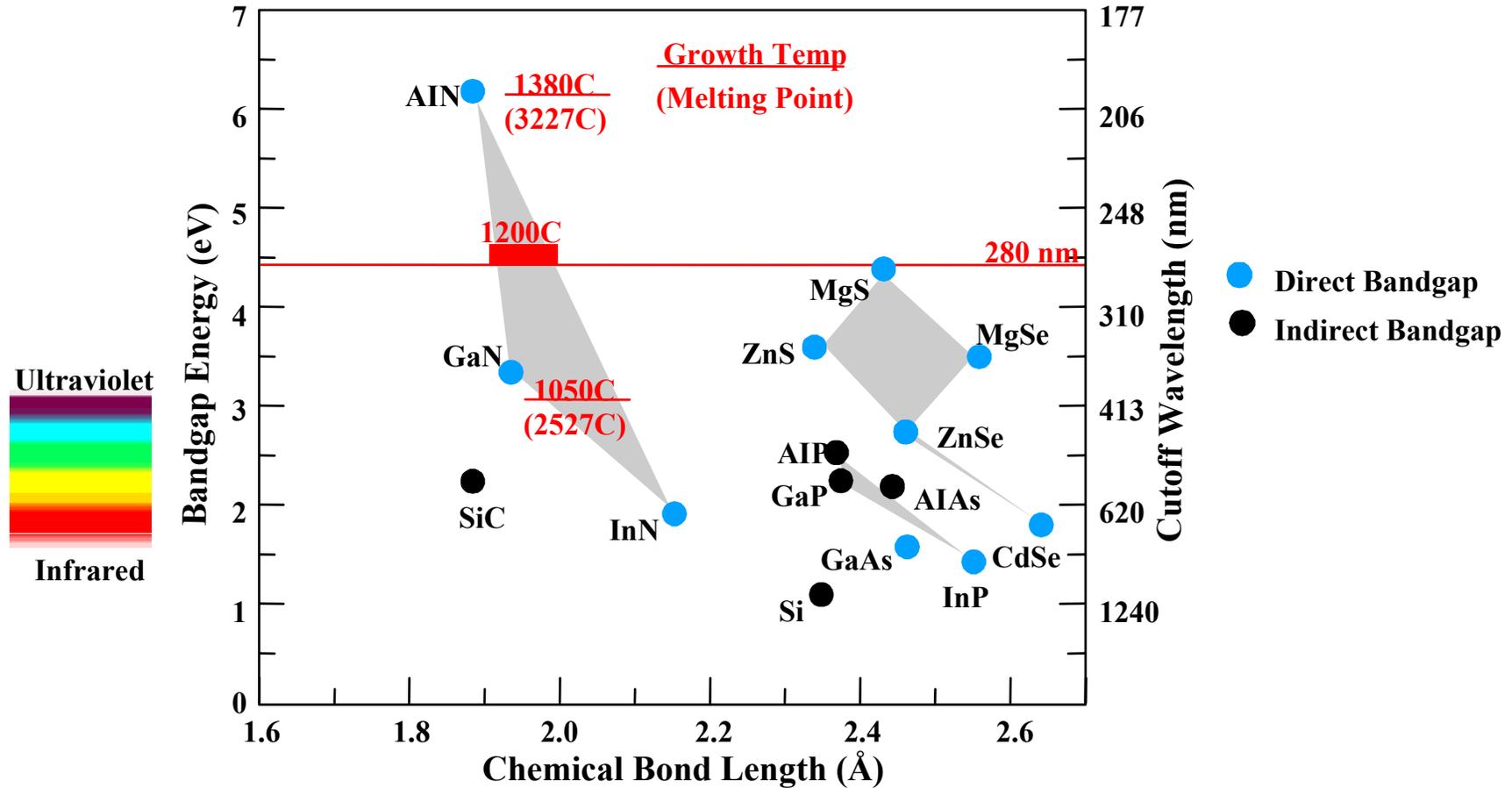


Ref: V.W.L. Chin et al., J. Appl. Phys. 75, 7365 (1994)

R.T. electron concentrations of $>10^{19} \text{ cm}^{-3}$ with $\mu > 100 \text{ cm}^2/\text{Vs}$ have been reported for $\text{Al}_{.37}\text{Ga}_{.63}\text{N}$ HVPE-grown films. (ref: B. Baranov et al., Phys. Stat. Sol. 49, 629 (1978).)



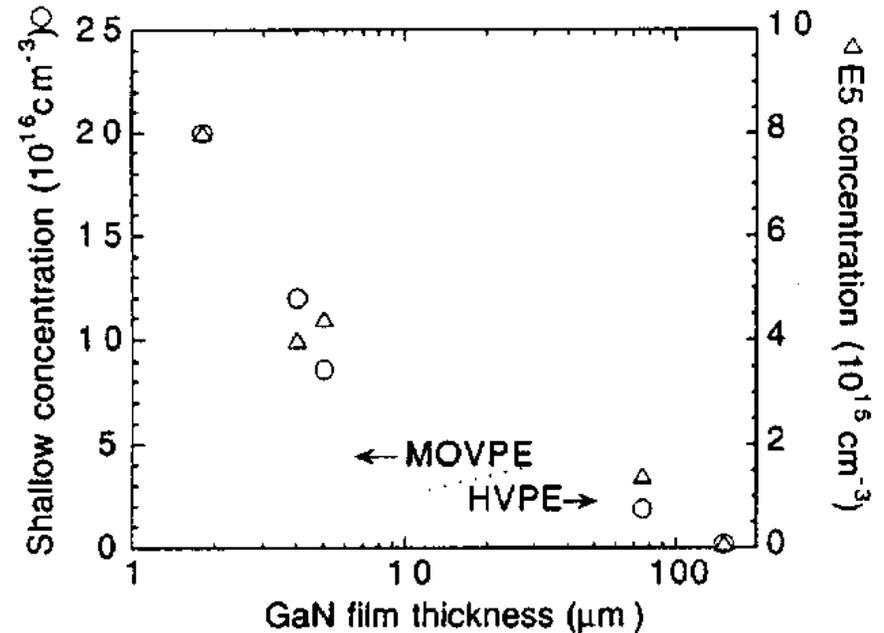
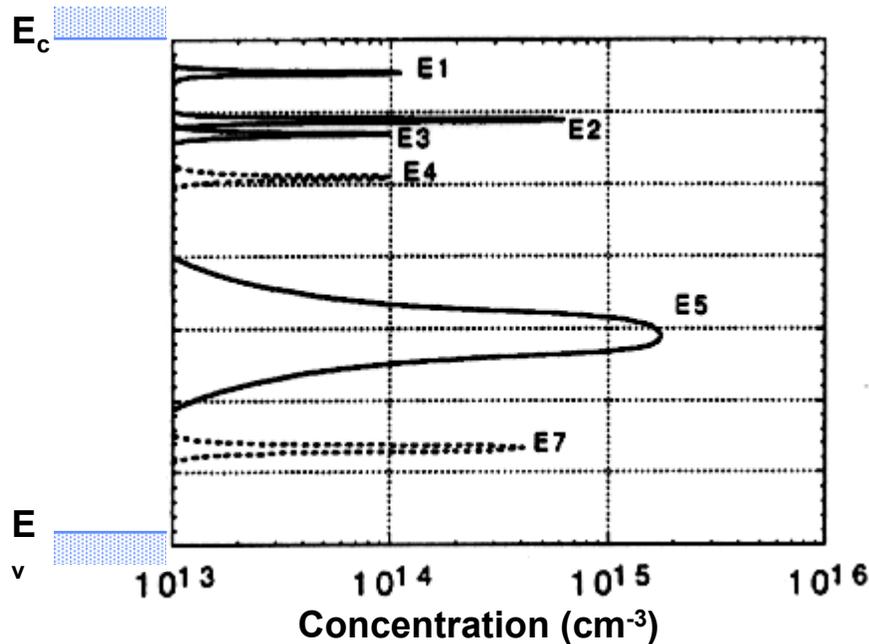
Bandgaps of common semiconductors



Scaling of optimized growth temperature of GaN by melting points of GaN/AlN suggest growth temperatures approaching 1200°C for $Al_{.4}Ga_{.6}N$.



Deep-Level Defects in GaN Films

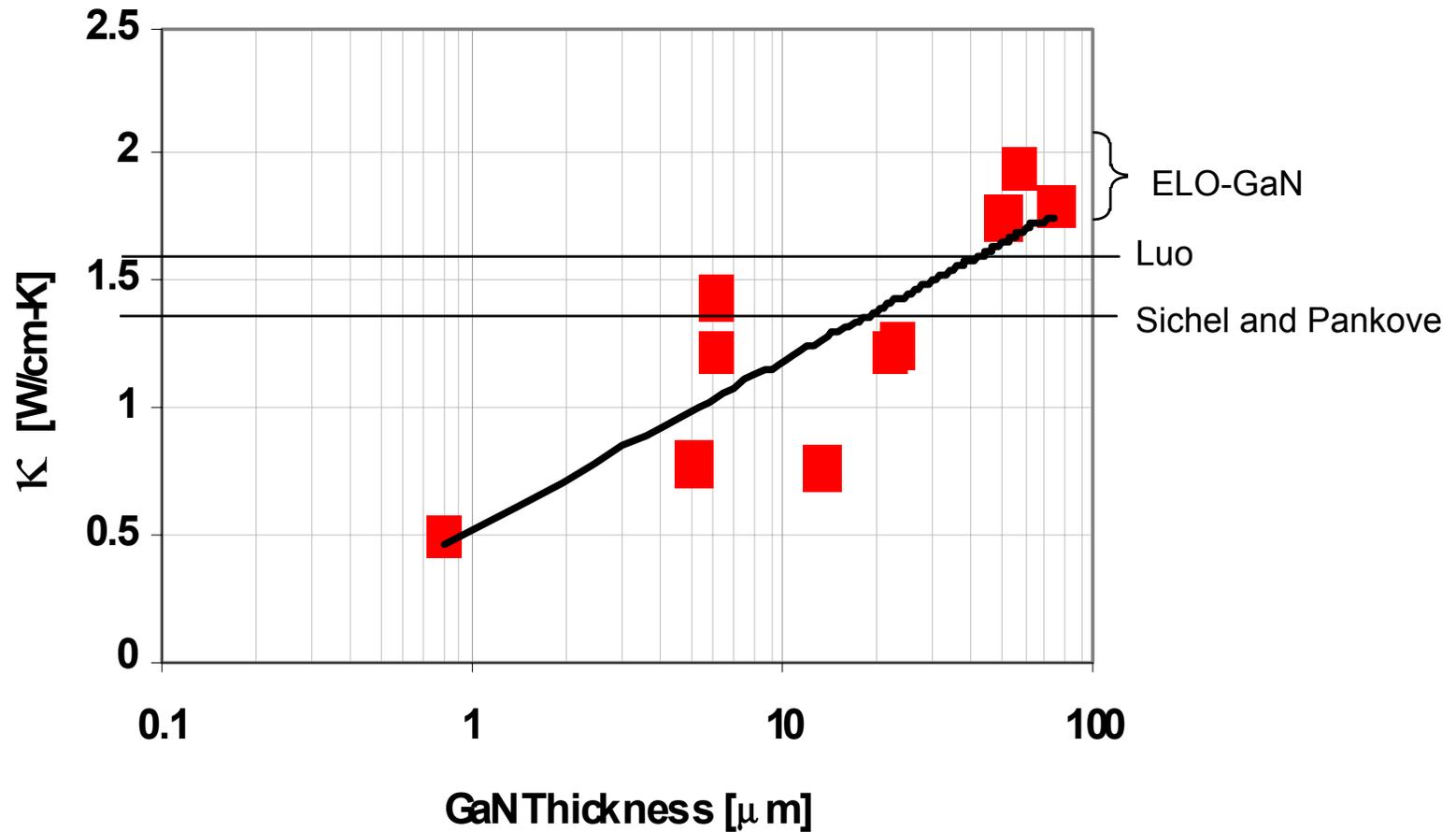


ref: P. Hacke et al., *J. Cryst. Growth* 189/190, pp. 541 (1998).

- Clear correlation between concentration of donor-like & mid-gap defects with thickness.
- Thick HVPE films afford substantial reduction of both these type of defects
- This will likely improve device stability/reliability



Thermal Conductivity of GaN

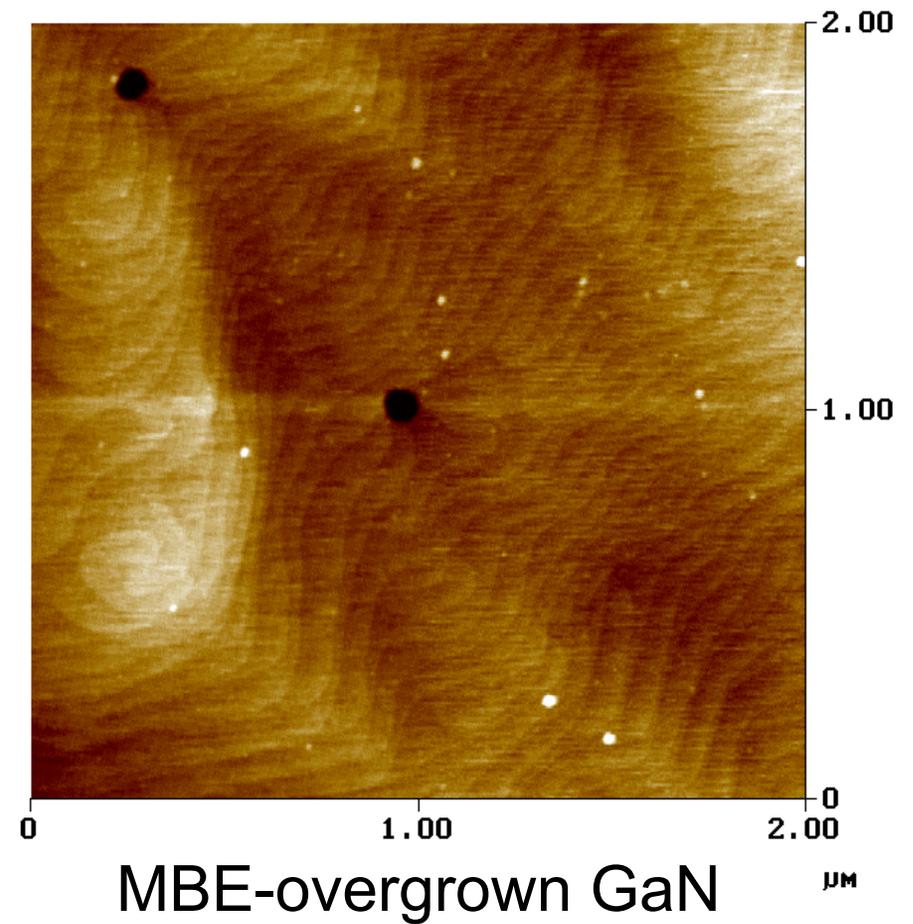
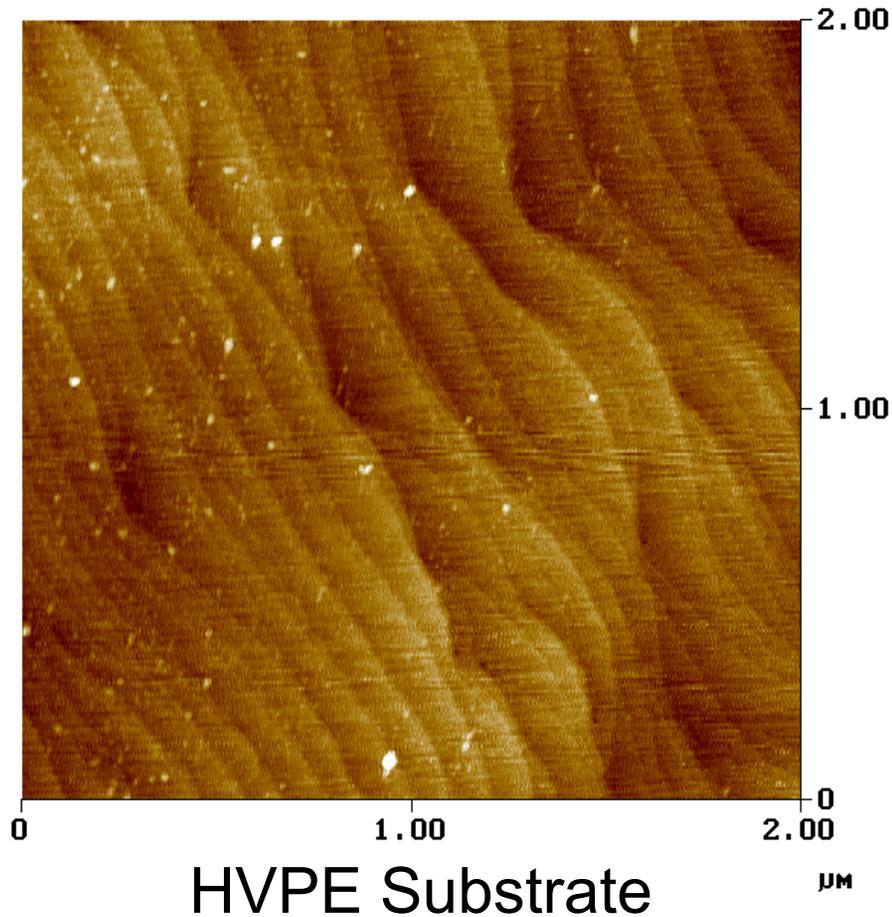


courtesy Brooklyn College of CUNY

MIT Lincoln Laboratory



Surface Morphology by AFM



Z scale 5nm

courtesy Lucent

MIT Lincoln Laboratory

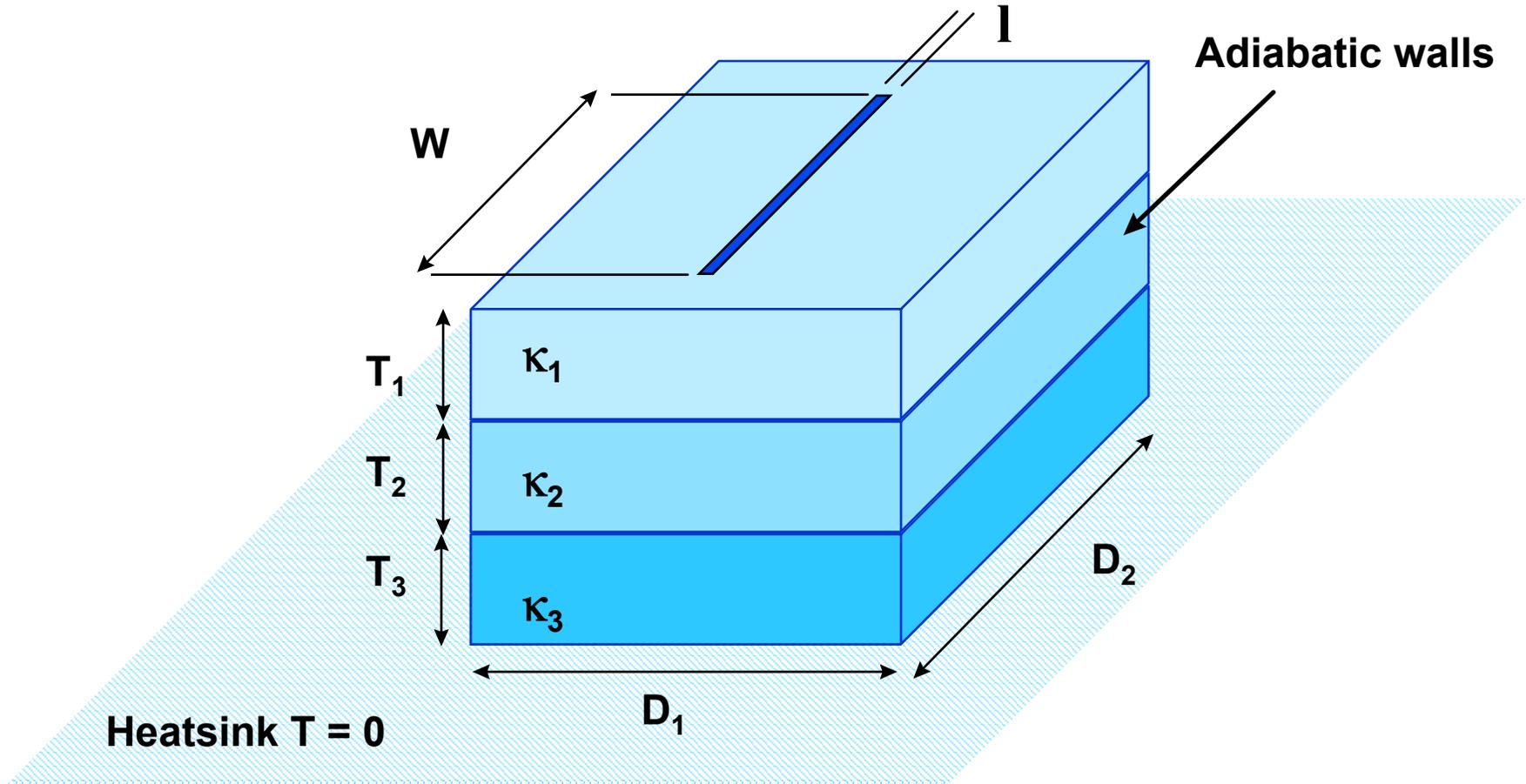


Summary

- **UV III-N light sources, while technically challenging will have significant DoD and non-DoD impact.**
- **Uniform linear-mode gain & UV Geiger-mode photon counting demonstrated with HVPE-grown GaN APDs**
- **Substrates development will be important for improving device performance**
-



Thermal simulation model

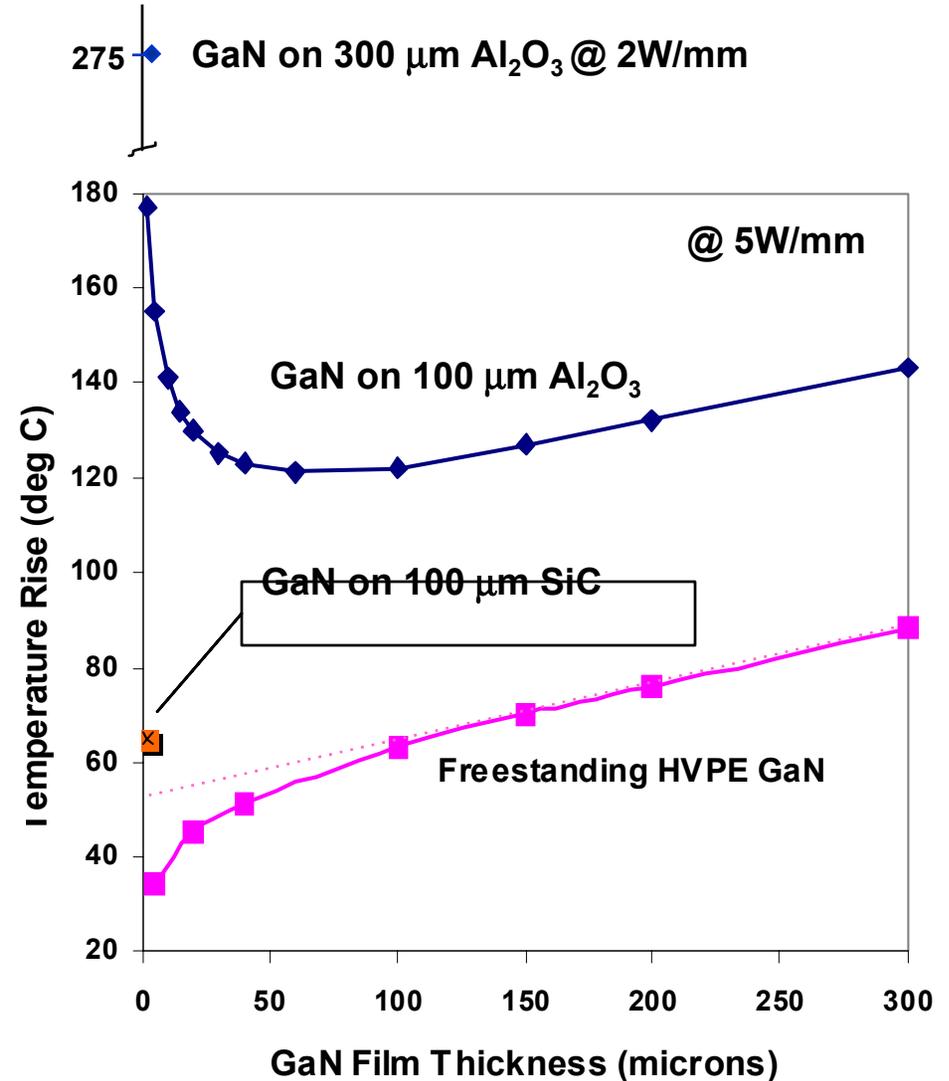
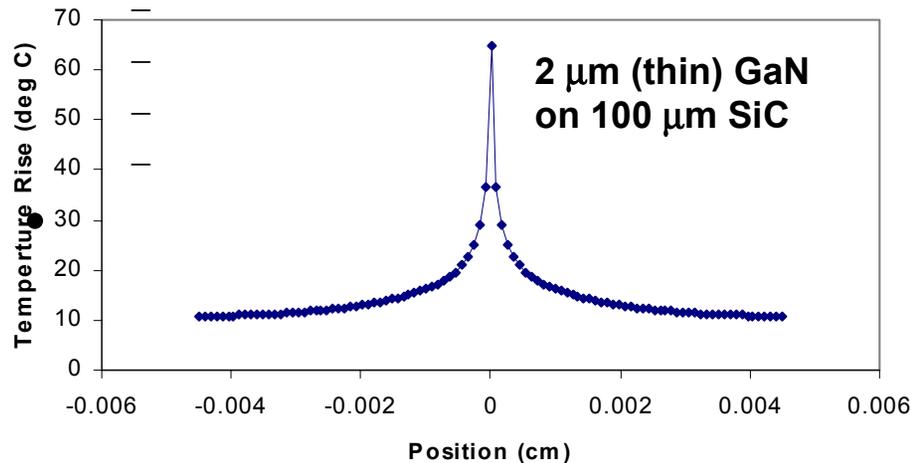




Modeled Temperature Rise Under Gate

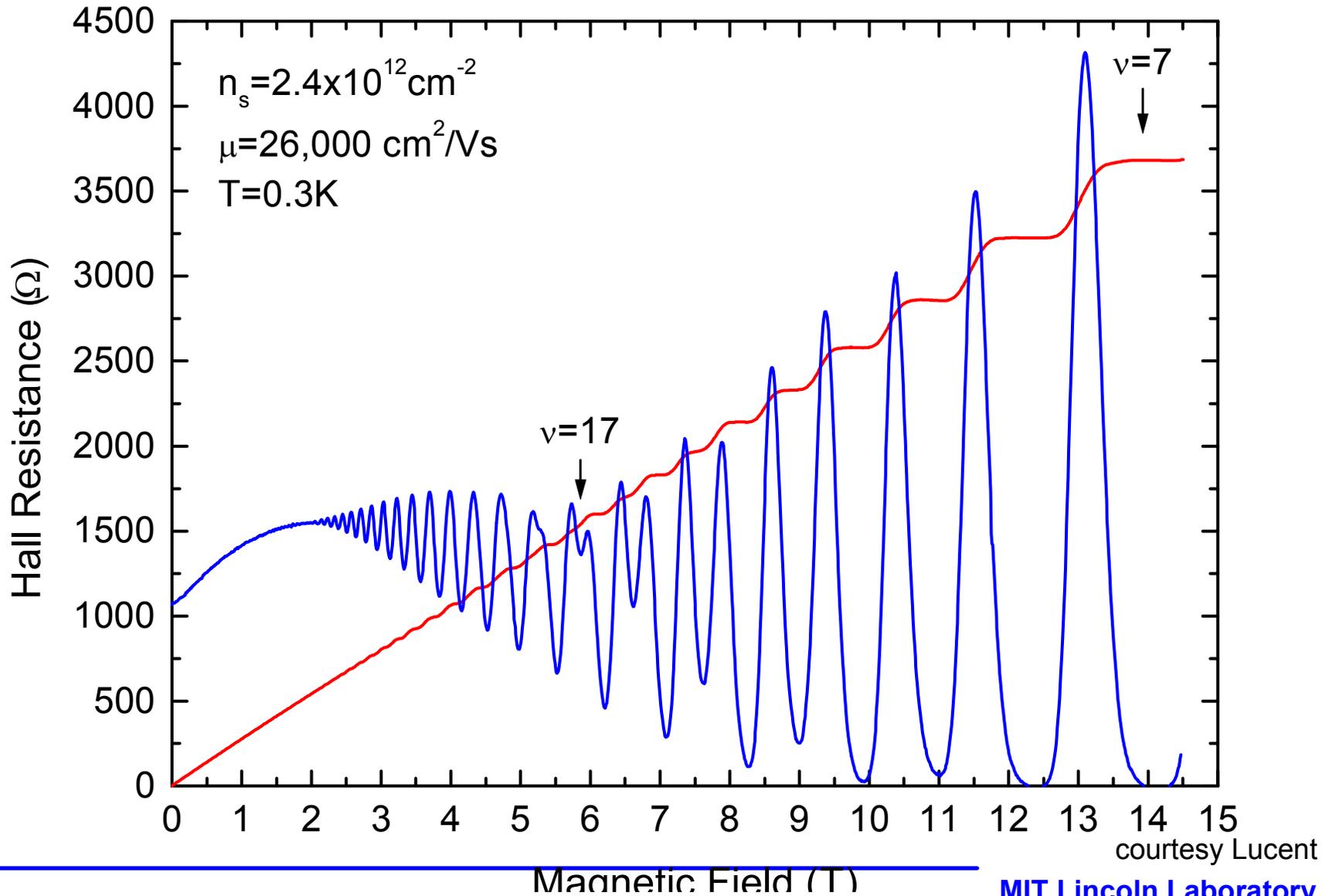
- Assumptions:**

- Large number of gate fingers
- Gate length $0.35 \mu\text{m}$
- Gate pitch $90 \mu\text{m}$
- Gate width $200 \mu\text{m}$
- Chip width $500 \mu\text{m}$
- Power dissipation = 5 W/mm
- κ (Thick GaN) = 2
- κ (Thin GaN) = 1.3
- κ (SI- SiC) = 3.3
- κ (Al_2O_3) = 0.4





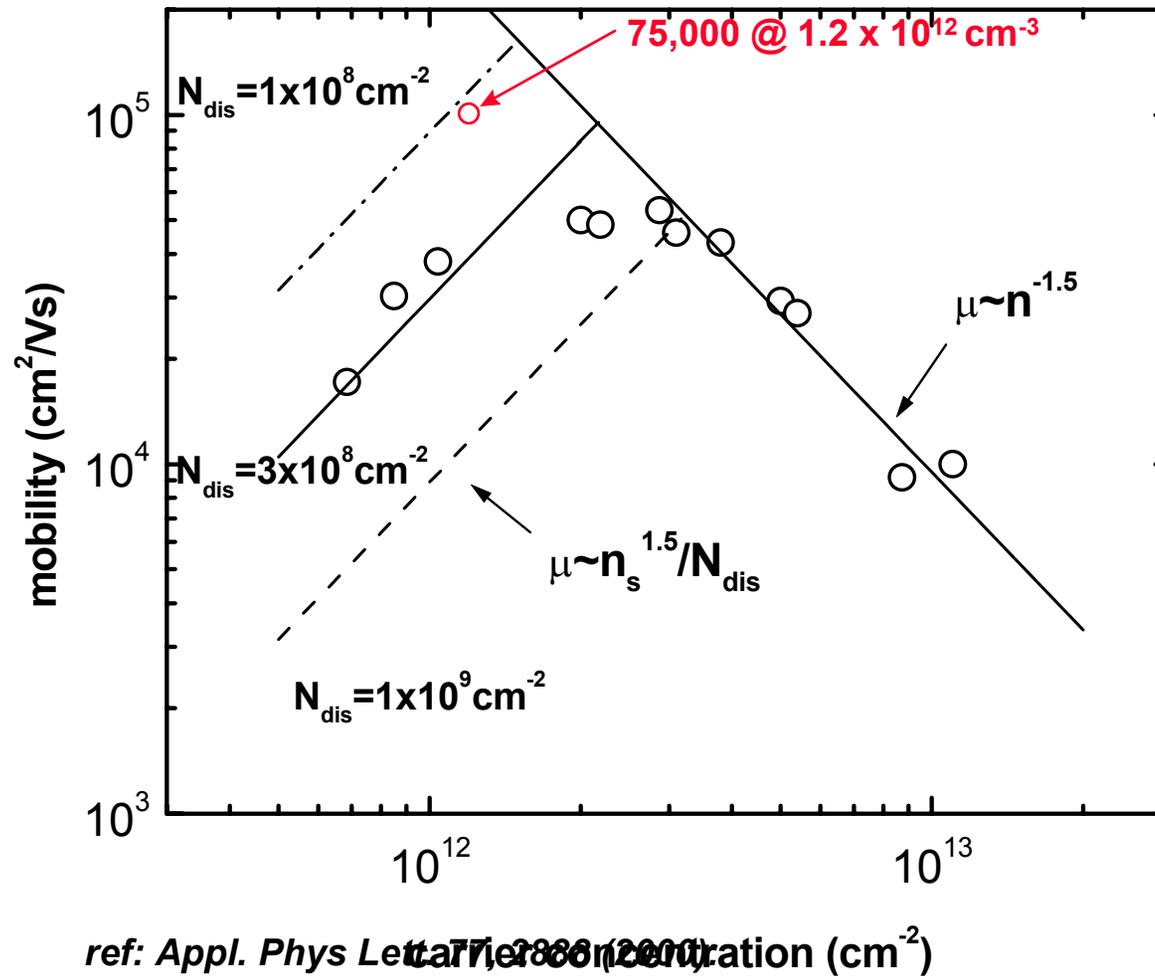
MBE AlGaN / GaN 2-DEG on HVPE Si-GaN



courtesy Lucent



Low-Temperature Mobility vs carrier density



courtesy Lucent



Laser-Separated Free-Standing GaN Films

- 130 microns thick epilayer with $\mu = 965 \text{ cm}^2/\text{V}\cdot\text{s}$ at 293K

